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NAVY-WIDE WORKSHOP ON HIGH PRESSURE BIOMEDICAL RESEARCH.(U)

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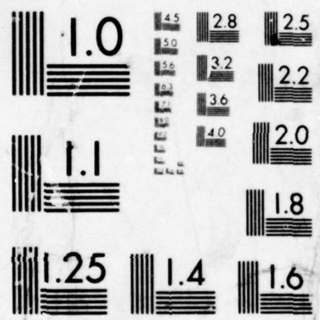
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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The report represents a summary of scientific and operational matters relating to improving man's ability to work underwater. The bulk of the report is centered about eight relevant discussion panel sessions: Physiological Criteria for Equipment Design; Cold Protection; Performance; Decompression; Decompression Sickness; Oxygen Toxicity; HPNS and Narcosis; and Future Trends.

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FOREWORD

On 9-11 March 1976, the Office of Naval Research and the Naval Medical Research and Development Command cosponsored a Navywide Workshop in High Pressure Biomedical Research at the Naval Coastal Systems Laboratory, Panama City, Florida. The objective of the Workshop was to foster the exchange of information between naval personnel engaged in manned underwater activities and scientific investigators conducting research on related problems in Navy supported laboratories.

The Organizing Committee of the Workshop is pleased to offer the following report of the proceedings to those individuals interested in the problem area. No attempt has been made to present a verbatim transcript of the stimulating and provocative panel discussions. Instead, each rapporteur prepared a brief, discursive resume covering the high points of the session for which he had responsibility. Each panel chairman has had the opportunity to review and fine tune the rapporteur's output to emphasize what the chairman felt were the important aspects. This has been done within the constraints on style and format imposed by the Organizing Committee.

The Committee hopes that this final report on the Workshop is an informative, easily read document of value to the scientific as well as the operational personnel interested in improving man's ability to perform underwater. We trust that the inclusion of the names, affiliation and addresses of all the participants will serve as a mechanism for establishing pathways for further information flow. It is felt that such an interplay between operational personnel and researchers will enhance the appreciation of the user's needs and the producer's potential, thereby helping to solve operational problems more readily.

R. C. Bornmann

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Office of Naval Research

ACKNOWLEDGMENTS

The success of a workshop depends largely on the willingness of the panel members, panel chairman and audience to participate freely and informatively while keeping to the point and staying within the constraints of the agenda. All of the participants at the Workshop performed admirably on this score and for this the Organizing Committee is most appreciative.

The Committee is very grateful to Admiral J. Edward Snyder, Jr., Special Assistant to the Undersecretary of the Navy, for his enthusiastic support of the Workshop. His Keynote Address set in proper perspective the important interrelationship in the Navy between the producer of scientific information and its operational user.

None of the stimulating interactions between participants could have taken place without the wholehearted cooperation of Captain Robert T. Quinn, Commanding Officer of the Naval Coastal Systems Laboratory, and his staff who hosted the Workshop. Special thanks are extended to Mr. Maxwell Lippitt, Jr., who played such an essential role in making the local arrangements and to Mrs. Lynda Coram and Mrs. Bette Delia, who were so important in the smooth functioning of the Sessions.

Last but not least our particular thanks go to Mrs. Kathleen Bowden Fear, Secretary to the Physiology Program at the Office of Naval Research, who has devoted so much time and effort (even after working hours) to the Workshop from its inception until the completion of this report. This has involved an endless procession of letters, forms, record keeping, drafts of speeches, and finally, this ultimate version of the report. We are all most appreciative of her help and cheerful attitude under pressure.

ONR/NMR&DC

NAVYWIDE WORKSHOP

ON

HIGH PRESSURE BIOMEDICAL RESEARCH

AGENDA

8 March 76

1800-2000	Registration	Holiday Lodge
1900-2200	Cocktails (Cash Bar)	Holiday Lodge

9 March 76

0800-1630	Registration	NCSL Auditorium
0800	Introductory Session Welcome Welcome Keynote Address	Dr. L. M. Libber, Chairman CAPT R. T. Quinn, CO, NCSL LCDR M. A. Paul, XO, NEDU RADM J. E. Snyder, Jr., SECNAV
0900	Navy Diving: Missions, Equipment, Procedures, Communications and Physiological Monitoring	Supervisor of Diving and NEDU Staff
1030	Coffee Break	
1045	Panel Discussion: Physiological Criteria for Equipment Design	CDR M. E. Bradley, Chairman LT E. Thalmann, Rapporteur
1215	Lunch	"The Long Glass"
1330	Panel Discussion: Cold Protection	Dr. P. Webb, Chairman LCDR K. Bondi, Rapporteur
1430	Coffee Break	

AGENDA (Continued)

1445	Panel Discussion: Performance	LCDR T. Berghage, Chairman LT J. Spencer, Rapporteur
1645	End of Sessions	

10 March 76

0800	Tour of Facilities	Hydrospace Lab and Ocean Simulation Facility
		(Continue at NCSL Auditorium)
1030	Panel Discussion: Decompression	Dr. C. J. Lambertsen, Chairman LT L. M. Fraser, Rapporteur
1200	Lunch	"The Long Glass"
1315	Panel Discussion: Decompression Sickness	CAPT J. Vorosmarti, Chairman LT J. Zumrick, Rapporteur
1445	Coffee Break	
1500	Panel Discussion: Oxygen Toxicity	Dr. J. Clark, Chairman LCDR D. Hall, Rapporteur
1630	End of Day's Sessions	
1800	Social Hour	Four Winds Restaurant
1900	Buffet Dinner Dinner Speaker	Four Winds Restaurant Miss S. Kronheim, Introduction CAPT G. Bond, MC, USN (Retired)

11 March 76

0800	Panel Discussion: HPNS & Narcosis	Dr. E. B. Smith, Chairman LCDR W. Hunter, Rapporteur
0930	Coffee Break	
0945	Panel Discussion: Future Trends	CAPT R. Bornmann, Chairman CDR C. Harvey, Rapporteur
1045	End of Workshop Sessions	

KEYNOTE ADDRESS

BY

REAR ADMIRAL J. EDWARD SNYDER, JR.
SPECIAL ASSISTANT TO THE UNDERSECRETARY OF THE NAVY

It's a pleasure to be here with you. Many of you know that my interest in Navy diving activities goes back a long way. My interest is still strong because I think of our diving capabilities as basic to effective naval operations.

Since the performer in these activities is the human, we have a grave responsibility for establishing valid definitions of human capabilities and limits in our missions. We also have the responsibility to provide the proper tools...hardware and procedures... for conducting safe diving missions. The biomedical research which the Navy supports is absolutely fundamental to the achievement of those goals.

I recognize the sacrifice of time away from important work that you are making in order to attend sessions of this kind and I appreciate your interest. A workshop like this can be a valuable source of information about what has been done and what is being done to solve problems. I think it's an excellent example of technology transfer, that we are trying so earnestly to accomplish these days.

The truth is that we have always been interested in transferring technology from one place to another. We have become more conscious of the term, today, because of executive interest in its service to the nation's economy. But the Navy's use of contract assistance to help us get things done is a matter of historical record and its continuance is represented by this workshop and your presence here, today.

It's the most obvious, and probably the most effective way to transfer technology since both Navy and the contractor come away from a project with identical knowledge about what can or cannot be done to solve a problem, or problems. Paraphrasing the Sara Lee commercial, "Nobody doesn't like avoiding unnecessary investment of resources and effort to get a job done". We all recognize there are plenty of places to spend money and time without using it to do the work that somebody else has already done. I am confident that your exchange of ideas, here, will help to avoid such waste of resources.

Another thing the Navy cannot afford to do is to maintain research and production facilities that would supply all of our needs for improving naval capabilities. Our business is defense and to meet our objectives we support the development of Sea Control Systems. Research required to help us develop them draws upon so many kinds of skills and facilities that are highly specialized, we cannot afford to maintain their existence throughout long periods of no use. It is more cost effective to call upon them in time of need, as we do in the contracting agreement.

In the Naval Oceanographic Program, we are singularly dependent on academic and private industrial sources for specialized research and development work that helps us to reach our goals. Nearly 50% of the Navy's underwater bio-medical research program is carried out by civilian institutions, through contract program administration by the Office of Naval Research. We will continue to rely on Navy skills and facilities to meet our objectives in diving and biomedicine, particularly where those skills and facilities need to be tailored to Navy's specialized and continuing requirements. We fully intend to call on the civilian research community, also.

Our funding for this coming fiscal year 77 should include contracting assistance in biomedical research at a level of nearly three million dollars and about three and a-half million for fiscal year 78 for civilian research. If you compare that with little more than two million dollars in biomedical funding support for private research from all other federal agencies you can see that Navy is still the heavy in diving and biomedical technology development.

As the Naval Oceanographic Program expands to meet increasing fleet requirements for oceanographic products and services, our need for private assistance in research increases, also. Secretary Marcy stated, last year, that the Navy's goal should be to contract for at least 65% of all of its research effort. It takes time to build research capabilities. All of you recognize the fact that it cannot be done by simply pouring money into a project, suddenly, unless skills and facilities are available.

In a draw-down of funding throughout the military services, one of the activities that has suffered greatly is research and development. But we are seeing a change in attitudes toward the need for keeping our technology competitive in the military and the economic arena of international relationships. Just last month, the Secretary of the Navy signed a Memorandum for the Chief of Naval Operations and the Commandant of the Marine Corps in which he said:

"Research is an important part of the overall Navy and Marine Corps research and development program, and the quality

and adequacy of size of the research effort are of the utmost importance.

Since research is an investment recognized as long-term, the Navy budget for research must be protected from incursions prompted by current deficiencies in development and production programs."

His intent is very clear, I believe. We cannot put aside the search for new ideas and we cannot delay the improvement of our knowledge about ocean influences on our operations...particularly, its influences on the human performer. That's what the Naval Oceanographic Program is all about and biomedical research plays a vital role in it.

We are concerned that our research in biomedicine continue to be directed toward the solution of specific problems, just as it must be with all Navy research efforts. The pursuit of knowledge for the sake of knowledge is fundamental to progress in human achievement but it needs to be considered an objective of individual and academic behavior, rather than a Navy mission. We need to call on you to help us uncover new ideas and, as contractors in biomedical research, to help us apply those ideas to the solution of specific problems in the improvement of our diving and other undersea capabilities.

The Naval Oceanographic Program is concerned with four major categories of oceanographic research and development: ocean science, environmental prediction services, oceanographic operations, and ocean engineering and development. Our broad objectives in the program are to provide the Navy with knowledge of its operational environment and to use that knowledge most effectively for improving the Navy's capabilities for defending national security. Our goals are concerned with learning how the sea influences our operations and how those influences can either be overcome or employed to our advantage.

Specific objectives of the program include: enhancement of weather prediction and reporting; significant improvement in underwater acoustics operations; better and faster ocean survey capabilities; the development of new and alternate sensor and communications systems, such as laser, infrared, and others to augment underwater acoustics techniques; better navigation technology; more compact, durable, reliable and efficient power systems for undersea operations; the development of improved materials, equipment and manufacturing techniques for use in all ocean areas; diver/swimmer and underwater life-support techniques and equipment; and improved surface vessels, handling systems, and deep submergence systems for increasing our undersea capabilities.

The term "Undersea Operations" keeps popping up in most of those objectives, so it is immediately apparent that submergence of the human performer, either in the open water or in some kind of vehicle is basic to those objectives. The highest price we can pay for any objective is the loss of human life. Since human life has no price...that is to say it is "priceless"...the loss of even one life is insupportable. That means we must be very sure of the capabilities and the limits of our personnel who perform undersea missions of any kind. It is absolutely basic to our plans and operations.

The bio-medical research, in which so many of you participate, is the source of our definition of those capabilities and limits. The results of your efforts provide much of the knowledge we must have to equip our personnel with technology and procedures that permit accomplishment of mission, without jeopardizing life or health. Most of those assets come, only, from laborious and time-consuming research and application of research findings, because we must be <u>sure</u> that we are right. But all of you know about these objectives and the pathways that lead us to them. I repeat them, here, to emphasize the Navy's deep concern for safe progress in diving and its related activities. Your efforts are helping us to meet our commitment to safety and excellence of performance.

The advertised Naval Oceanographic Program is funded at about 200 million dollars, annually. It is divided roughly as funding of 40 million dollars for ocean engineering...60 million for ocean science...about 10 million for R&D in environmental prediction, and the remaining 90 million for oceanographic operations. The Oceanographer of the Navy is major claimant for the 90 million dollars which supports ocean survey efforts.

The Ocean Science Program is that part of the overall Navy research program which is identified as oceanographic research. The ocean engineering portion is a part of the naval development program which is responsible for developing oceanographic systems like submersibles, and search, recovery, and salvage equipment. The Oceanographer serves as a coordinator of these activities, monitoring progress and defending program funding in direct liaison with the Assistant Secretary of the Navy for R&D.

Within the broad responsibilities of the total oceanographic program, the Oceanographer helps to establish policy concerning support of specific research and development activities. Our goal is to make sure that knowledge and technology are being developed in the most orderly and efficient manner possible. We would like to work with contractors who can give us the best product for our money

and time invested. That doesn't necessarily mean the biggest and longest established institutions. The Navy would like to benefit from the achievements of all who contribute knowledge that is useful in our efforts to improve diving capabilities and to safeguard the lives and health of our operating personnel.

We are committed to those goals and I believe our funding profile in bio-medical research supports that commitment. Our participation is still stronger than other performers in the field and its strength will continue to grow. I would like to see others match our commitment because that would help us by sponsoring accelerated progress throughout the field of bio-medical research and development. Until such growth is accomplished, the Navy will continue to be the "heavy" in diving and bio-medical research. We have no choice if we are to sustain our Navy's capabilities.

The results of this workshop can be of substantial assistance in meeting urgent and long range objectives in Navy diving. Most sincerely, I wish you all success in making this meeting a productive exchange that is rewarding to all of us. I look forward to your continued support of Navy objectives.

PHYSIOLOGICAL CRITERIA FOR EQUIPMENT DESIGN

Chairman: CDR M. E. Bradley, MC, USN

Rapporteur: LCDR E. Thalmann, MC, USN

Members: Dr. C. J. Lambertsen
CAPT W. Mazzone, MSC, USN (Retired)
Dr. G. Moeller
Mr. J. Quirk
Dr. H. Rahn
CAPT W. H. Spaur, MC, USN

PHYSIOLOGICAL CRITERIA FOR EQUIPMENT DESIGN

In his opening remarks, CDR Mark Bradley set forth as the goal of this session to bridge the gap between the engineer and the physiologist. The data available to the engineer in terms of physiologic parameters is at present rather limited, making equipment design more pragmatic than scientific. As evidenced by some of the presentations in this session the physiologist has a great interest in man's performance at depth and is at present pursuing studies which may well result in improved standards for diving gear. As CDR Bradley pointed out, however, the research process is a long and tedious one and does not produce results without a certain lag time. Technology has enabled man to descend to depths which a few years ago were considered unattainable. The lack of good physiological criteria at these depths led to the design of equipment, which, after much accumulated experience, has proved inadequate in many respects. This, along with increased emphasis on diver health and safety, has led to the rather recent quest for more stringent and better researched standards. The participants in this panel session succeeded in outlining the problem at hand and indicated both methods of attack and some preliminary results of just completed studies. The panelists themselves did not set forth any specific criteria and the engineer will have to wait some time for hard standards which he can put to use in equipment design.

Captain Walter Mazzone opened the session with a pictorial history of the evolution of diving apparatus. His talk brought forth two main points the first being that the basic design of diving gear has changed very little over the years and the second being that the needs of the diver have not changed significantly. In particular, Captain Mazzone noted the need for a lightweight diving helmet, a need which was recognized many years ago but which is only now being actively pursued.

Dr. Hermann Rahn outlined the approach being used at the State University of New York (SUNY) at Buffalo in analyzing physiologic performance underwater. Interest at SUNY at Buffalo has generally focused on the diver wearing SCUBA in the swimming position. The main thrust has been on the effects of immersion and static lung loading (breathing at a net over-or under-pressure). As Dr. Rahn pointed out the effects of immersion alone are quite profound. There is an increase in thoracic blood volume and a 50% increase in cardiac output. The effects of these changes alone may be significant but in the actual diving situation they are coupled with breathing resistance, increased gas density and other impediments imposed by the breathing apparatus. Separating the effects of these variables is difficult but a vigorous attempt is being made at SUNY at Buffalo. They have

equipped their unique pressure chamber with a pulmonary function testing apparatus which minimizes external breathing resistance. Using this apparatus, divers are studied under exercise conditions at mouth pressures ranging from -40 cm H_2O to +40 cm H_2O from the surface to 200 FSW. The information gathered from this study may help in determining what acceptable static lung loadings are at various depths, as well as elucidating some of the pulmonary function changes which occur at increased gas densities under exercise conditions.

Dr. Christian Lambertsen reviewed some of the studies already completed on divers working at great depths. Dr. Lambertsen noted that the great number of changes occurring at depth require an experimental approach which is very sophisticated and which in itself is an engineering problem. He stressed that studies should be done under a set of standard conditions so that results would be comparable. Pointing out some of the limitations imposed by increased gas density on man he noted that, in spite of a generalized decrement in pulmonary function, the diver who is unencumbered by an external breathing apparatus fares pretty well and can do useful work down to gas densities equivalent to thousands of feet of seawater. Although admitting that there are many unknowns in working at such depths, he stressed that effort should be placed on helping the diver do better what has already been demonstrated he is capable of, rather than holding back because of concern for other problems which may not be a factor in actual practice. With regard to breathing apparatus, Dr. Lambertsen saw no reason why equipment could not be designed so that it put no additional impediment whatsoever on the diver's respiratory system.

Captain William Spaur talked about the actual testing of diver breathing gear as done at the Navy Experimental Diving Unit. NEDU is the organization responsible for testing of all diving gear used in the fleet or approved for Navy use. NEDU also sets standards as put forth in the Diving Manual for all aspects of diving. Since NEDU must approve all diving gear for the Navy, they in fact, set the standards for Navy equipment. As Captain Spaur pointed out in the question and answer period, the standards used by NEDU are constantly changing and are based on the best available information which exists at the time. In the actual testing of equipment, it is first tested "off the shelf" on the diver down to its normal working depth. The equipment is tested in the attitude for which it was designed (i.e., prone for SCUBA, upright for hard hat) under exercise conditions up to oxygen consumptions of 3 liters/minute (severe exercise conditions). A baseline is established at 10 FSW and then the performance at increasing depths is compared to that baseline. In order to evaluate performance objectively the diver is usually instrumented so that

parameters such as heart rate, respiratory rate, inhalation and exhalation effort, inspired or helmet CO_2 and arterial pCO_2 (where practical) can be measured. These measurements along with subjective observations are then used in determining if the equipment is acceptable or not and what modifications could be made to improve its performance. Since there are no set standards for breathing gear, each piece of equipment is analyzed both on its own merits and using data accumulated from past experience. Any design changes thought necessary are made and further testing is done on a mannequin and breathing machine. Using the human data as a baseline, improvement is detected by measuring those particular parameters which were felt deficient. Thus, once a human baseline has been established, modification can be done quickly and efficiently and human testing only be done again during actual operational testing.

The last two speakers, Mr. John Quirk and Dr. George Moeller addressed themselves to the topics of Diver Tools and Habitats respectively. Both of these speakers indicated a need for more information on the human engineering aspect of equipment design. In particular Mr. Quirk gave the following list of items which would be useful to him in designing equipment:

1. How much effort can a diver exert on different types of bottoms carrying different loads?
2. What sizes and weights can the diver most efficiently handle?
3. How hard can a diver be expected to work at any given depth?
4. What is the optimal bouyancy for tools?
5. What are acceptable values for the magnitudes and durations of rotatory and squeezing forces?
6. What are the effects of various orientations in zero visibility water?
7. What are the best types of instrument displays?
8. What are safe noise levels?
9. What are the shock hazards while submerged?

Synopsis of Discussion

When asked about hydrogen's capability to extend diver's depth capability Dr. Lambertsen felt that factors other than pulmonary ones, such as central nervous system problems and hydrostatic forces, would probably limit depth. Later in the session a brief account was given of the dyspnea which occurred during the NEDU 1600 FSW dive in New Orleans that did not seem to be accompanied by a decrement in pulmonary function sufficient to explain the dyspnea by itself. No explanation could be offered but the thought was expressed that this dyspnea might be vulnerable to direct investigation with pharmacological agents. Continuing with factors other than pulmonary which might limit depth, other members of the audience cited instances where normoxic (.21 ATA oxygen) gas mixtures proved insufficient at depth. One dive was an 800 foot $He-O_2$ dive conducted at the Royal Naval Physiological Laboratory in Portsmouth, England and the other a 198 foot air dive conducted at New London, Connecticut. Although no explanation was evident at the time, it was felt that the effect was at the cellular level.

The second major topic of questioning concerned the role of the physician in the development of equipment. When faced with this question Captain Spaur replied that hard standards are not yet available and that evaluation of diving gear is based largely on the subjective observations of trained personnel. Captain Spaur saw the Diving Medical Officer at NEDU as filling this essential role. Dr. Lambertsen saw the physician as someone who could provide a liaison between the physiologist and engineer.

Finally, the point of what levels of arterial pCO_2 were acceptable was brought up. Captain Spaur replied that NEDU arbitarily chose the clinical criterion of arterial pCO_2 greater than 50 mm Hg as constituting respiratory failure. This standard has shown itself to be reasonable during numerous physiological tests, but there is no evidence that the 50 mm Hg level is absolute since some divers can work with a higher arterial pCO_2 without unusual distress.

The problem in establishing a good set of physiological criteria for diving equipment is a formidable one. Although man can work at great depths, little is known about the man-apparatus interface at extreme depths. Even at shallower depths, diving equipment may break down when pushed to its extremes. As data slowly accumulate on man's performance using various types of diving gear, standards are upgraded and applied to new equipment. This process is especially frustrating to the engineer who may see standards changed part of the way through the development of a piece of gear by the medical or physiological

personnel involved in the testing procedure. This is often the result of new aspects of diver performance and impediment coming to light as equipment is pushed to higher work rates and deeper depths. At present, it seems unlikely that the physiologist could supply the engineer with a set of standards which would enable him to design and build an apparatus which would meet all its expectations. Thus, the engineer and physiologist must work jointly and remain flexible in their approach to equipment design, so that the best performance can be gotten out of the diver using a particular piece of gear.

COLD PROTECTION

Chairman:	Dr. P. Webb
Rapporteur:	LCDR K. Bondi, MSC, USN
Members:	Dr. K. Cooper Dr. S. K. Hong Mr. W. Jenkins CDR L. Raymond, MC, USN

COLD PROTECTION

This report will generally be concerned with the physiology of animals and man in cold environments and as such, will perhaps serve as a basis for those planning operational missions and those designing and manufacturing thermal protection gear. The study of cold water immersion is made easier for the hyperbaric physiologist since cold water at 1000 feet of sea water (FSW) is about as cold as water at 10 FSW. This is not true of the hyperbaric gaseous environment where thermal transfer increases drastically as one dives to greater and greater depths.

It is normally considered by the diving world that thermal problems center around the problem of being cold. At a recent meeting, however, hyperbaric scientists and operational divers alike were astonished to hear of a report from the North Sea that two divers died of heat stroke upon entering a hot hyperbaric chamber at approximately 400 FSW. This incident brings home the fact once again, that thermal transfer in a hyperbaric environment is rapid and dangerous at the deeper diving depths.

While thermal protective gear has advanced considerably in the last few years, it still remains relatively unsophisticated and inadequate for many diving situations. Advances in thermal protective equipment for divers will depend on the research of physiologists that can provide insight to those engineers involved in the design of that equipment.

There are a number of operational missions where the ideal situation of providing both passive (e.g., a wet suit or a dry suit) and active (e.g., a free flooding hot water garment) thermal protection cannot be met. It is also not feasible to attach a supplementary heating device to the already encumbered diver who must work in remote areas on a survey or a reconnaissance mission, frequently after parachuting to his final destination. An account was given where an exorbitant amount of money, time and effort were spent to transport divers to an Arctic site only to find that their actual time in the water was severely limited because their "hands felt like large pieces of wood" and they could do very little useful work after a very short period of immersion.

There has been little physiological research done on man while he has been acutely immersed, unprotected, in cold (16°C) water. Dr. Keith Cooper

of the University of Calgary, Alberta, has shown that under these conditions the tidal P_{CO_2} and skin temperature are reduced. If the subjects were preheated in a sauna, their respiratory response, as indicated by the percent change in end tidal P_{CO_2}, was greatly attenuated and returned to near normal levels after a short time. If subjects were outfitted in jeans, sweatshirts and anorak before immersion, the response to cold immersion, as indicated by the mean percent change in ventilation, was again somewhat attenuated. At approximately 20 minutes, however, as the subject began to swim and move cold water through his clothing both hyperventilation and shivering increased markedly. During the swimming exercises it was necessary to increase the oxygen consumption to 1.8 l/min before the P_{CO_2} returned to normal. In another group of experiments the maximum voluntary contraction of one forearm during immersion in 30°F water was studied using a gripping device. After about six minutes of immersion, grip strength fell off at a mean rate of 1.6-2.0%/min. An interesting phenomenon noted in these studies was that the grip is not relaxed in the same manner as in warm water. It was also noticed that when the isometric grip in cold water reached the point where only 40% of the maximum warm water squeeze could be maintained, shivering was shut off. In practical terms, this phenomenon may remove a valuable source of supplemental heat during work in cold water.

While it is quite evident from the foregoing that with regard to cold water immersion many simple problems are yet to be solved and basic questions are yet to be answered, there is an equal void in our knowledge about thermal problems in hyperbaric chamber environments. One fact which is well recognized, however, is that the *ambient temperature in such an environment* must be continually raised as the pressure is increased in order to maintain thermal comfort and balance. Thermal balance at high pressures, however, is precarious at best as demonstrated by Drs. Suk Ki Hong and Lawrence Raymond and others. Dr. Hong has shown that when the ambient temperature is altered or set at a few degrees from the empirically determined comfort temperature, there are physiological compensations as manifested in alterations of oxygen consumption, rectal temperature, skin temperature and catecholamine release. Dr. Raymond demonstrated that by simply removing shirts and ceasing regular activity during metabolic measurements at pressure, the rectal temperature falls from its initial temperature at the start of the measurement period and the scrotal temperature rises. It was also shown that while a dry suit affords some protection from cold water (15°C) at 1 ATA, much of this protection is lost when one dives in this suit at 11 ATA. The rectal and mean skin temperature drop much faster and to a further extent

at 11 ATA as compared to 1 ATA (skin heat transfer and conductance were also shown to be increased with these suits at 11 ATA).

Heat loss by convection (both skin and respiratory) are increased during hyperbaric operations, while heat loss by evaporation and radiation are decreased. Metabolism in a comfortable hyperbaric environment is generally unchanged.

Two interesting points concerning weight loss and fluid balance under hyperbaric conditions were discussed by Dr. Raymond. First, it was pointed out that, due to the principle of displacement put forth by Archimedes, the body is normally buoyed up by the gas which surrounds it. When the density of this gas is increased, the buoyancy effect is increased proportionately so that at 50 ATA in 100% helium, a normal man will have experienced an apparent weight loss of 0.8 Kg! Obviously, upon decompression, he will have "gained" back the weight. Second, in a previous report Dr. Raymond hypothesized that the diuresis often seen during hyperbaric operations was due to a higher level of breathing causing central venous distention and suppressing the production of ADH. In a subsequent study, it has been shown that ADH levels are increased under these conditions, not signaling the kidney to put out a concentrated urine--the kidney does not respond. It was further pointed out that norepinephrine levels were also increased some three to four times normal during this period, and it is known that norepinephrine makes the renal tubule refractory to ADH.

Synopsis of Discussion

A question was raised as to why there should be such a large difference in ambient temperature needed for thermal comfort between French and American divers. Dr. Raymond responded that it may be a combination of physical and physiological factors in that (a) French divers were generally leaner and had a higher ratio of surface area to mass and (b) wall temperatures were warmer in the American chambers. An additional comment from the audience indicated that differences in the way chambers are maintained for thermal comfort make it difficult to compare data from different dives unless all the variables are accounted for.

Considering the great fall in P_{CO_2} observed by Dr. Cooper in men immersed in cold water, the pH should have increased to 7.7-7.8. He was asked, therefore, if any signs of tetany appeared in the subjects. Such signs were evident, Dr. Cooper said, and were manifested by improper responses to psychomotor tests, the degree of errors being proportional to the extent of the lowering of the P_{CO_2}. Dr.

Cooper was also queried as to why preheating in sauna diminished the ventilatory responses. He admitted that while the increased skin temperature was out of the range of cold receptors, the skin temperature had to pass through that range as the subject remained in cold water, and he therefore could not give a proper answer to that question. He did speculate, however, that the location of the receptors with regard to blood vessels may play a more important role than surface temperature per se. Dr. Webb wanted to know if these subjects were all naive, and Dr. Cooper responded that a great deal of variability was noticed because the subjects differed markedly in their experience in diving and cold water exposure.

Information was requested from the audience on the existence of any data on hypothalamic temperatures at increased pressures, since increased respiratory heat loss might affect this area of the brain and therefore might effect temperature perception. The panel responded by saying that there were, obviously, no human data available and that little reliable tympanic membrane temperature data existed.

The panel and the audience were reminded that respiratory heat loss was still a factor to be contended with. Even though some excellent studies have been conducted, an investigation should be made to determine just how far cold penetrates down the respiratory tree and to find out what the optimal breathing temperatures should be according to the mix and ambient pressure of a dive. With regard to possibly calculating how much heat may be lost from the respiratory tract, Dr. Raymond pointed out that our knowledge of the physical constants such as viscosity, density, coefficient of volume expansion, etc. is limited when it comes to high pressure situations, especially when we are dealing with binary and ternary mixtures. Mention was made from the audience that the Canadians have had a good success in rewarming cold divers by heating the inspired gas. Dr. Webb commented that care should be exercised to prevent overheating or excessive drying of the mucous lining when employing these techniques.

PERFORMANCE

Chairman:	LCDR T. Berghage, MSC, USN
Rapporteur:	LT J. Spencer, MSC, USN
Members:	LT R. Carter, MSC, USN Dr. D. Fletcher LCDR T. Hawkins, USN Dr. G. Moeller CDR A. Smith, USN Dr. W. Vaughan

PERFORMANCE

LCDR Thomas Berghage, the Panel Chairman, opened the session by suggesting that the Panel be retitled "Human Performance Information; Who Needs It?" He gave a brief description of the performance tests used in the past and expressed the view that performance tests fall into four functional categories, which evaluate: (1) the diving environment, (2) the diving equipment, (3) the operational procedures, and (4) the divers themselves. LCDR Berghage stated that the U. S. Navy had been gathering human-performance data since 1937; he questioned whether the material produced since that time has done much more than occupy space on library shelves. His challenge to the panel was "What has human-performance testing done to help the diver perform his task?"

Dr. Dorothy Fletcher of the University of Pennsylvania discussed how breathing gas mixtures under hyperbaric conditions can affect subgroups of performance tasks. She stated that most research has been devoted to the analysis of change in basic motor and sensory tasks, while higher cognitive tasks such as those involved with memory have been ignored. There is a need to describe more accurately, by going to the field, what types of strategies the diver is using to solve various cognitive tasks. By better understanding the threshold range and limits of capability of diver performance, researchers can develop more usable information that may aid future diving missions. A variety of tasks and subtasks can be analyzed by presenting them via a computer hook-up. In this way the experimenter can observe how the subject is attempting to solve the tasks.

Dr. Arthur Bachrach of the Naval Medical Research Institute stressed the point that not only should performance be measured, but correlations with physiology should be made. He stated that an important question still to be answered is "What effect does the wearing of heavy diving equipment have in terms of physiological cost?" This question could be answered by a biomechanical approach whereby extent and degree of arm movements in diving suits is analyzed and correlated with the stress it places on the heart. Certain types of tasks and subtasks done by divers in water will yield a better quantification and others for gross as well as moderate work capabilities. One such test, which is currently in use, is a pipe puzzle where the measurement is limited to time to completion of the task. Dr. Bachrach described a new underwater task called SP2 that has been designed to assess underwater performance in either the chamber or the open sea.

Performance

Dr. George Moeller of the Submarine Medical Research Laboratory at New London reported using performance tests to assess diving procedures during repeated exposures to 188 FSW in air. In his studies psychomotor and mathematics tests both show that with repeated exposures the decrement in performance becomes less. Short-term memory also shows some adaptation. A state-dependency effect is often seen whereby what is learned under one condition is performed best under that condition. Daily exposures show improved performance, but a generalized narcotic effect is still observed. These findings appear to have implications for those who plan dives and establish dive procedures.

LT Robert Carter of the Experimental Diving Unit surveyed the literature and found that the attrition rate in Diving School is 55%. He suggested that performance tests could be used to evaluate divers in two different ways. The first application involves the use of tests for selecting candidates for diver training. He questions whether certain performance tests can be used to screen such candidates, since tests based on physical fitness or aptitude have failed as predictors of training success. He stated that a need exists to insure that all candidates (1) have an interview with the Diving Officer, (2) be exposed to O_2 pressure-tolerance tests, and (3) be well acquainted with the type of diving equipment used on dives. The second application of performance tests involves the determination of whether the working diver is fit to continue the job. Two important variables that should be considered are psychological stress, which acts to narrow the diver's world, and the effects of cold exposure. A mock-up of real-life stress experience may help to predict those divers who might be adversely affected by a dive. A suggested monitor for the effects of cold would be skin temperature, to see whether a sudden temperature drop will produce selected types of deficits in performance.

LCDR Thomas Hawkins, an operational UDT Officer, pointed out that he is concerned about getting his men into the water to do the task and return safely. Research has not provided answers to questions that he has, which include: Do tables of compression, saturation and decompression exist for divers who go into the water from altitude? What is the best type of diet for a diver on a mission? How can a Diving Officer deal with psychological stress and anxiety in his men? He states that basic and applied research have not provided the fleet with necessary and usable information that can be understood by the Diving Officer.

Performance

CDR Albert Smith of the Submarine Development Group One also pointed out that fleet-usable data is needed. The environment, personnel and equipment all act to impose limitations on operations. One very important restriction is that the diver is the worst possible judge of his own physical limitations. CDR Smith stated that there may be a need for a device to provide information to the diver on his own physiological state; that definitive predictors of diver performance should be available; that these predictors should be in a language and format that is readily interpreted by the divers. In addition, he believes a training program is needed to develop better verbal communication at depth--a speaking guide for divers.

Dr. William Vaughan of Oceanautics, Inc., pointed out that his review of the literature revealed that human performance is generally discussed in terms of basic human abilities and not diver tasks. The important questions of how many packs swimmers can carry or how fast swimmers can swim are not answered. He believes that studies need to be done on the ability to read a compass at depth. Most studies show that the effects seen in a laboratory cannot always be transcribed to the water. Although the use of a factor-analytical approach has made it possible to break tasks into components, there still is a need to know what types of procedures the diver goes through to solve certain tasks. A desirable goal may be a data bank, which can provide information on equipment needed for a specific task or mission, based on the established validity of certain tasks relevant to diving.

Synopsis of Discussion

In summarizing the Panel's deliberations, LCDR Berghage stated that the participants had succeeded in identifying a number of problems in the diving human performance research program. The operational people had indicated the need for human performance data, the various behavioral scientists on the Panel had outlined the ways in which human performance information could be used. It appears, however, that a gap still exists between the data the scientists are gathering and the information the operators need. LCDR Berghage suggested that the lack of use of human performance information was due to one or both of the following factors: either the wrong type of information is being gathered, or the information that is gathered is presented in the wrong form. From the discussion of the Panelists, both of these factors, to a certain extent, seem to contribute to the problem. To bridge this gap between the operational community and the research community, a research management program must be developed to deal with both of the above factors. Establishment of research objectives should ensure that the right data are collected. Getting the results

from this relevant research to the operational community in an appropriate form is a more complex problem. Fleet operators contend that they don't have the time or technical resources to translate complex technical reports into usable equipment or procedures. The researchers, on the other hand, state that they lack the time and funding for such an effort. Also, many of them lack a full appreciation of the operational environment. The responsibility for this information-translation function must be assigned to someone. As it now stands, each community thinks the responsibility belongs to the other.

Captain Robert Bornmann responded to LCDR Berghage's summary by suggesting that an established but inactive OPNAV committee should be rejuvenated to define the operational requirements.

LCDR Berghage ended the session with these comments: "Although this Panel did not solve any of the problems of underwater human performance, it did identify some fundamental issues in the research management program. These issues are basic to responsive research, not only in the behavioral sciences, but in all scientific fields. If the Panel accomplishes nothing more than getting action on the following two items, it will have been a success:

(1) Stimulate OPNAV to identify fleet-related diving research objectives.

(2) Bring about assignment of the responsibility for translating research results into operational capabilities."

Decompression

Chairman: Dr. C. J. Lambertsen

Rapporteur: LT L. M. Fraser, MSC, USN

Members:
Dr. P. Bennett
LCDR T. Berghage, MC, USN
Dr. W. Fife
CDR C. Hedgepeth, USN (Retired)
Dr. B. Hills
Dr. K. Smith

DECOMPRESSION

The session was opened by Dr. Christian Lambertsen with a description of the format of the session. He described studies of decompression theories as being a mixture of physics, physiology and pathology. A star was drawn with "bubble" in the middle of the star signifying its central role in decompression sickness. Around the apices of the star were shown: inert gas exchange, exertion temperature, circulation and hormonal influences to signify the interacting, contributing roles. The type of tissue and environment were discussed as factors contributing to the formation of bubbles.

CDR Charles Hedgepeth spoke as a representative of the operational world, and pointed out that decompression sickness was not only of danger to the subject but in addition, disrupted operations for the remainder of the unit. He recommended further work in developing safe, efficient schedules for non-saturation as well as for the saturation modes of operation. In addition, he recommended better methods of validation of our decompression schedules and for predicting the effectiveness of the schedules in field use. Commenting on factors that lead to bends, he indicated a need for attention even to psychophysiological influences on local circulation.

Dr. Brian Hills discussed some of the results of his studies with "zero-supersaturation" theory of decompression. The basic thesis is that we must know if and when we form bubbles during decompression, because if even non-clinical bubbles are formed, the entire basis of the Haldanian methods of calculating decompression tables is affected. His work with Kangaroo rats as indicators of clinical symptoms shows that symptoms occur during decompression at or soon after the point of tissue saturation is reached. He stated that when bubbles are present the gases dissolved in the tissues can move by two pathways: into the bubble or into the blood. This means that (in contrast to classical theories which say come up another stop when the supersaturation ratios are low enough) we should stay deep to increase the driving force for the collapse of the bubble.

Dr. Kent Smith discussed research supporting the work of Dr. Hills. Several slides were shown which demonstrate the relationship of a schedule to the number of bubbles heard by a doppler detector. A standard U. S. Navy Table (220 ft/20 min) caused many bubbles starting about the 30 to 40 foot stop and continuing long after surfacing. Contrastingly, a table with a gradual ascent to 80 feet with a much slower

ascent to the surface, with the same elapsed time, showed far fewer bubbles.

Dr. Smith showed some photographs of bone sections illustrating the damage caused by gas bubbles. His major thesis was that "Any substantive decompression causes bubbles and that bubbles cause tissue damage". Dr. Smith suggests that in this respect bubble formation is enhanced by: (1) fast ascents, (2) long first ascents, and (3) long periods with large tissue supersaturation.

LCDR Thomas Berghage discussed a survey describing the type of diving the U. S. Navy is doing. In summary, about 99% of the dives are to depths of less than 200 feet. About 7% require decompression, for a total of 4,300 dives. Of these dives needing recompression, 49% used standard air tables and 29% used He/O_2 tables. 78% of the decompression is still performed in the water. There were 35 cases of decompression sickness, an incidence of 0.2%. Saturation dives accounted for about 20% of the time under pressure and accounted for 20% of the decompression sickness cases.

Dr. William Fife discussed some of his experiences in performing dives with hydrogen-oxygen mixtures to depths of up to 1000 feet. The lower flammable limit for these mixtures is 5%. A level of 3% was chosen for safety and is normoxic at 200 feet. The dives were performed by pressurizing to 200 feet with another medium and then purging the chamber with the hydrogen-oxygen mixture. Decompression was likened to that required with helium but more critical at the greater depths (700 feet). There may have been some problems with isobaric decompression sickness when the change to the non-flammable medium was too rapid.

Dr. Peter Bennett described the evolution of a specific Subsaturation Decompression Table (500 ft/30 min). The initial trials were on a Haldanian type table of some 670 minutes duration. The table was lengthened to some 1100 minutes before decompression sickness was eliminated and was considered far too long to be of practical value. The table was eventually modified by including a diffusion limited shallow portion with the Haldanian deep portion. The final successful version of the table is about 730 minutes long and is in current use in the North Sea area.

Dr. Lambertsen concluded the session by stating that decompression studies covered the range from very disruptive, even lethal effects, through simple reversible bends to gas elimination without even microscopic effects upon tissues. He emphasized that true research toward major advances in decompression theory and practice must be supported separately from trials and specific "tables". Validation of concepts will remain an important function requiring precise design and

control.

Synopsis of Discussion

The questions from the audience were directed to the central topic of bubble formation and growth as well as the validity of designing decompression tables using pain as the indicator of bends rather than the presence of bubbles. Left unanswered were questions such as: Is either pain or bubble detection a completely satisfactory endpoint? Can bubbles in the body create any important effects without causing pain or other symptoms?

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DECOMPRESSION SICKNESS

Chairman: CAPT J. Vorosmarti, MC, USN

Rapporteur: LT J. Zumrick, MC, USN

Members: Mr. W. Bergman
Dr. C. Chryssanthou
CDR J. Hallenbeck, MC, USN
Dr. W. H. Johnson

DECOMPRESSION SICKNESS

Decompression sickness is an occupational hazard of divers. Only recently has active research into the mechanisms and treatment of decompression sickness begun.

The value of a physician in managing diving accidents during operational diving cannot be overemphasized. Areas of concern to the occupational diving community include developing an approach to bends cases not responding to usual treatment, oxygen convulsions during bends treatment, and more effective therapy for air embolism cases particularly where treatment is delayed. Considerable effort is now devoted toward solving these problems.

Investigations into the pathophysiology and non-recompression treatment of spinal cord decompression sickness has been conducted at the Naval Medical Research Institute over the past five years. Their approach taken has been three-pronged. First, a dive profile reliably producing spinal cord bends was developed. Second, studies into the vascular changes produced by this profile were conducted. Finally, studies on the factors influencing microcirculatory reperfusion have been begun.

The dive profile developed consists of a rapid descent to 220 FSW for 40 minutes followed by a rapid ascent. When serious bends were noted, recompression to 70 FSW to control the cardiovascular symptoms and a final slow ascent to the surface was instituted. This profile reliably produced spinal cord bends in dogs with a low mortality rate.

Pathophysiological studies conducted on these dogs include: investigation of plasma volume changes, cinevenography, cinematography of the epidural veins in laminectomized dogs, and autoradiographic blood flow studies. These studies indicate that a significant plasma volume shift occurs in spinal cord bends but not in pain only bends. Vascular abnormalities noted in spinal cord bends start as the appearance of small discrete bubbles in the epidural veins. The bubbles slowly grow and coalesce producing sludging and, finally, stasis. Morphologically, the change noted in the spinal cord was one of white matter hemorrhage and grey matter sparing. The areas of cord damage one would assume from clinical symptoms were borne out by these observations.

Numerous pharmacologic agents were tried to ameliorate the symptoms produced. Steroids, platelet inhibitor VK 744, alpha blockers, beta adrenergic agents, phosphodiesterase inhibitors, and

methysergide all seemed to have little affect on the course of the illness. Only plasma volume restoration produced a response and then only to prolong life, not to affect the spinal cord symptoms.

Since CNS bends seem to be primarily a vascular disease, emphasis is now placed on the factors which affect tissue reperfusion after varying periods of ischemia. Such research may prove fruitful not only in bends treatment, but also in understanding the pathophysiology of air embolism, another vascular disorder.

It has been established that mechanisms resulting in decompression sickness cannot be explained by the presence of bubbles alone. It now appears that bubbles precipitate biochemical changes in blood cells. Much research in defining hematologic alterations in blood and their role in causing bends has been conducted at Beth Israel Hospital in New York. These studies indicate that the presence of bubbles set into motion several pathways which result in the production of a substance or substances called Smooth Muscle Activating Factor (SMAF). Some possible pathways are shown below:

Inadequate Decompression
↓
Gas Bubbles
↓ ↓ ↓

Vascular Obstruction and Tissue Anoxia	Mechanical Disruption of Cells	Activation of Thrombocytes in Blood

→ SMAF Production ←

Several findings by this group substantiate the role of vasoactive substances in bends:

(1) Increased levels of vasoactive substances have been isolated from mice with bends.

(2) Nitrogen bubbling of blood produces SMAF.

(3) Injection of SMAF into mice increases the incidence and severity of bends and results in increased mortality.

(4) SMAF injection in mice produces many of the alterations seen in bends.

Increased vascular permeability due to SMAF may explain the plasma shifts observed by other researchers. Resulting hemoconcentration predisposes to vascular stasis which may promote further bubble growth. In addition, pulmonary edema may result leading to anoxia and decreased inert gas elimination.

A better understanding of the role of SMAF in decompression sickness will provide a logical basis for the use of drugs in treating serious bends. Research by this group indicates that the use of drugs which inhibits SMAF production decreases mortality significantly in bent mice. In addition, the administration of SMAF inhibitors prior to a dive serves to lower the incidence of bends in mice. Care should be taken, however, in extrapolating these data to humans. Utilization of drugs may prove valuable in treating decompression sickness where recompression is either not available or is delayed, or as a means to limit decompression sickness incidence.

Inner ear decompression sickness is an infrequent occurrence. However, with increasing depths of dives its incidence is expected to increase. At the University of Toronto, researchers are investigating some of the functional alterations and the morphologic changes in the inner ears of monkeys exposed to a 900 foot helium-oxygen dive.

After the dive, most monkeys appeared normal. However, in 25% of the monkeys decreased postural equilibrium was displayed and they tended to assume forced postures. Electronystagmographic studies showed decreased postrotatory nystagmus and increased spontaneous nystagmus post dive in all monkeys. In animals sacrificed one week later, post dive alterations were found in both the vestibular and cochlear portions of the inner ear. In the ampulla of the semicircular canals, gross perilymph hemorrhage was a constant finding. Endolymph hemorrhage was a common though less constant finding. Morphologic changes characterized as dense ragged alterations of the cupula were also reported. Another group reports finding bubbles in the perilymph. In the basal end of the cochlea, hemorrhage into the scala tympani was noted but the organ of Corti appeared normal.

Future studies anticipated in inner ear decompression sickness include:

(1) Sacrificing monkeys at varying intervals to follow the cause of morphologic alterations.

(2) Changing inspired gases trying to induce ear damage.

(3) Measurement of the size of the cochlear aqueduct.

(4) Development of a technique to measure cochlear damage.

(5) Examination of human temporal bones from diving fatalities.

(6) Development of treatment techniques.

In general then, it can be anticipated that research efforts of these investigators and others are moving toward a clearer understanding of the pathophysiology of decompression sickness which will improve the therapy of this disease state.

OXYGEN TOXICITY

Chairman: Dr. J. Clark

Rapporteur: LCDR D. Hall, MSC, USN

Members:
- Dr. O. Brown
- Dr. J. Hackney
- Dr. S. Mendoza
- Dr. C. Schatte
- CDR M. E. Bradley, MC, USN

OXYGEN TOXICITY

The chairman opened the session by reviewing the general characteristics of oxygen poisoning. Prolonged exposure to a toxic oxygen pressure can disrupt metabolic activity and ultimately destroy any living cell. The nature of overt manifestations of oxygen poisoning is determined by oxygen partial pressure, duration of exposure, and the relative susceptibilities of different tissues and organs. Toxic effects develop more rapidly as the inspired partial pressure of oxygen (PO_2) is elevated. In general, the use of oxygen at partial pressures of 3 atmospheres or higher is limited by toxic effects on the brain and its use at pressures of 2 atmospheres or less is limited by pulmonary oxygen poisoning. Nevertheless, it is important to recognize that other organ systems and functions are also susceptible to oxygen toxicity and, under certain conditions of oxygen pressure and exposure duration, may be seriously impaired before the occurrence of significant neurological or pulmonary effects.

It should also be recognized that many factors can alter the rate of development of oxygen poisoning. Agents which hasten the onset or increase the severity of toxic effects include adrenal hormones, hypercapnia, and hyperthermia. Other agents or procedures which delay or attenuate the effects of oxygen poisoning include drugs that block the transmission of adrenergic nerve impulses, anesthesia, and intermittent exposure to a less elevated or normal P_{O_2}. At the present time, intermittent exposure appears to be the most practical and effective procedure for increasing the duration of oxygen exposure without concurrent increments in the intensity of toxic effects.

Although one obvious means of avoiding oxygen poisoning would be to prohibit exposure to elevated oxygen pressures, this approach would also eliminate the usefulness of oxygen. CDR Mark Bradley described several operational situations in which hyperoxic gases are employed. These include the use of semi-closed and closed-circuit scuba at shallow depths, saturation diving, decompression from saturation and shorter dives, and therapy of diving accidents. The oxygen pressure-exposure duration relationships encountered in diving operations vary from multiday saturation dives with inspired oxygen pressures of 0.3-0.4 atmospheres to therapeutic applications of 2.0-3.0 oxygen atmospheres for periods of a few hours.

Results of studies designed to evaluate the effects of various normal dietary constituents on susceptibility to pulmonary oxygen

poisoning were reviewed by Dr. Christopher Schatte. These studies employ survival time in mice breathing oxygen at 1.0 atmosphere as an index of dietary efficaciousness. Survival time was increased by supplementing mouse diet with the metal, selenium. Supplementation with vitamin E, vitamin K, methionine and cystine was without effect. Development of a more sensitive index of pulmonary oxygen poisoning is currently underway with initial efforts directed toward the evaluation of early chemical changes in the washings from lung bronchi of oxygen-exposed rats. Future research goals also include the identification of interactions between specific dietary components which provide protection, and delineation of the cellular mechanisms which are responsible for these effects.

Dr. Jack Hackney summarized findings relevant to the effects of oxygen breathing on alveolar cell division in mouse lungs. Previous studies have shown decreased cell division in the lungs of oxygen-exposed animals and related *in vitro* studies showed inhibition of the biosynthesis of the genetic material, deoxyribose nucleic acid (DNA), presumably mediated by an initial depression of protein synthesis. Since oxygen-poisoned animals eat less and lose weight, the effect of starvation on alveolar cell division was evaluated. Results show that complete food deprivation produces about the same weight loss and decrement in cell division as does exposure to oxygen and that both stresses combined produce even greater effects on body weight and alveolar cell division. Thus, the decreased cell division found in oxygen-exposed animals is partly an indirect effect caused by inadequate nutrition. Future plans include studies of oxygen effects in experiments designed to minimize the influence of starvation, and correlation of functional and structural changes in the lungs of oxygen-poisoned animals.

The use of the toad urinary bladder as a model system for the study of oxygen effects on membrane function was discussed by Dr. Stanley Mendoza. Preliminary results show a dose-dependent inhibition of sodium transport across the toad bladder by exposure to oxygen pressures of 5 to 10 atmospheres for up to 4 hours. Although overnight exposure to 1 atmosphere of oxygen had no measurable effect on sodium transport by itself, inhibition occurred more rapidly during a subsequent exposure to oxygen at 5 atmospheres. Intermittent reductions of ambient P_{O_2} to normoxic levels for 1 to 15 minutes alternated with 4 to 60 minute periods of hyperoxia delayed the onset and reduced the severity of sodium transport inhibition. Future research will include studies at oxygen pressures of less than 5 atmospheres, evaluation of various protective agents, determination of oxygen effects on other toad bladder functions, and testing the ability of the toad bladder to recover from oxygen poisoning.

Oxygen Toxicity

Dr. Olen Brown described a series of experiments which employed microorganisms (*E. coli*) as a model system for the study of cellular sites and mechanisms of oxygen poisoning. Exposure to 4.2 atmospheres of oxygen inhibited biosynthesis with abrupt cessation of growth before there were significant decrements in cellular respiration, glucose transport, and energy production. The biosynthetic pathways therefore appeared to be the sites which were most susceptible to oxygen poisoning. Nutritional supplementation was used to identify sites of inhibition. Addition of the 20 common amino acids provided protection against hyperoxia and specific deletions revealed critical requirements for branched-chain and aromatic amino acids. Future plans include additional investigations of oxygen effects at susceptible sites in the biosynthetic pathways of nucleic acids and other proteins. The potential relevance of data obtained from bacterial systems to oxygen poisoning in mammalian systems is also under study.

Synopsis of Discussion

Discussion was opened with a brief summary of the previous presentations and indication of their interrelationships. Although hyperoxia is toxic to all living cells, its great usefulness can be exploited without harmful effects if safe pressure-duration relationships are not exceeded. Applied information is needed to define and extend the safe limits of oxygen exposure. Basic information is required to understand better the mechanisms of oxygen poisoning and to develop more effective methods of protection. Several questions and comments related to specific toxic effects of oxygen. Prolonged exposure of animals to an oxygen pressure of 400 mm Hg has caused irreversible pulmonary structural changes and even lower levels of hyperoxia may not be completely safe. Some forms of adaptation with increased oxygen tolerance may actually involve pulmonary damage which lowers arterial P_{O_2} during oxygen breathing. It was pointed out that, although intermittent reduction of the inspired P_{O_2} to lower or normal levels can effectively extend the duration of safe hyperoxic exposure, no known procedure or agent will completely prevent the ultimate occurrence of oxygen poisoning. Concern was expressed about the cumulative effect of hyperoxic exposure during a dive and the subsequent therapeutic use of hyper-oxygenation during or after the decompression period. It was suggested that the cumulative effects of repeated oxygen exposures are probably not strictly additive, since some recovery should occur between exposures. Finally, it was again emphasized that, although the toxic potential of hyperoxia should be respected, the useful properties of this gas can be exploited safely and effectively.

HIGH PRESSURE NERVOUS SYNDROME (HPNS) AND NARCOSIS

Chairman: Dr. E. B. Smith

Rapporteur: LCDR W. L. Hunter, Jr., MC, USN

Members: Dr. P. B. Bennett
Dr. R. Brauer
Dr. J. Kendig
Dr. C. J. Lambertsen
Dr. H. Rahn
LT H. S. Stevenson, USN
Dr. J. R. Trudell

HIGH PRESSURE NERVOUS SYNDROME (HPNS) AND NARCOSIS

The problem of narcosis was initially encountered while diving on compressed air. With the introduction of helium-oxygen breathing mixtures narcosis ceased to be a depth-limiting factor. The majority of Navy diving is at depths less than 200 feet so that until recently the major emphasis on developing saturation diving techniques resulted in a situation where available technology had surpassed operational requirements.

Currently, operational requirements in industry and, to a lesser degree, in the Navy have surpassed available technology. As a result, dives below 650 feet where the high pressure nervous syndrome (HPNS) appears are occurring more frequently. At this point interest in inert gas narcosis reappeared because of the rediscovery of the antagonism of pressure and anesthesia and, in the light of this antagonism, the use of small percentages of inert gas in breathing mixtures to circumvent HPNS effects. The purpose of this session is to examine recent developments in our understanding of HPNS and narcosis with attention to the use of narcotic gases to ameliorate HPNS.

There is a basic need to know more about the relationship between pressure itself and the action of anesthetics as they might affect the nervous system. The research reported by Dr. Joan Kendig aimed to clarify pressure/anesthetic interactions on excitable cells. In the first series of experiments, nerve fibers entering a complex of nerve cell bodies in a ganglion of a rat were stimulated electrically. Recordings were made of the voltage produced by the conducted action potential in the entering fiber and the response in the appropriate fiber leaving the ganglion. A second series of experiments used an isolated nerve/muscle preparation (phrenic nerve with diaphragm in the rat) from which measures of muscular contraction after nerve stimulation were measured. In each group of experiments data were gathered at 1 ATA, 1 ATA plus anesthetics, 200 ATA and 200 ATA plus anesthetics. The conclusion from these experiments indicated that the addition of anesthetics to ameliorate HPNS symptoms may be helping by markedly suppressing synaptic transmission.

To help understand what was happening to the nerve membranes during synaptic transmission, Dr. James Trudell has been studying changes in the internal motion of phospholipid model membranes induced by pressure and/or anesthetic agents. A distinct difference in the

membrane fluidity developed depending on whether the membrane was exposed to hydrostatic pressure or gas pressure. Hydrostatic pressure decreased membrane fluidity in every case while helium pressurization led to slight increases. Adding nitrogen to the helium in the proper proportions restored the model membrane fluidity to the control value. Anesthetics, on the other hand, were found to increase fluidity markedly and in rough proportion to the anesthetic potency of the agent.

Two sets of experiments involving in vitro cellular effects and one experiment on animal behavior were described by Dr. Hermann Rahn. The first set involved voltage clamping of squid axons which permits a measure of the current associated with the ionic movement across nerve membranes. When the axon was clamped at 150 ATA, the action potential produced on stimulation was prolonged while the resting potential and the maximum Na^+ and K^+ conductance remained normal. These results imply a kinetic process involving a gating mechanism that appeared to reduce conductance rate.

The second set of experiments described by Dr. Rahn involved the effect of pressure on the sinus node (the pacemaker cells) of the mouse heart. Normally, pressure slows heart rate (bradycardia) but when the node was pressurized at 10 ATA with nitrous oxide, this anesthetic reversed the pressure induced bradycardia. Finally, by tabulating the running behavior in mice exposed to a trimix ($O_2/He/N_2$) at 100 ATA, the trimix was shown to reduce running activity by about 50-60% in otherwise completely normal appearing animals. He/O_2, on the other hand, reduced running activity by 90% at 100 ATA. These animals showed normal behavior otherwise.

All of these studies indicate that the HPNS is a complex entity. Dr. Ralph Brauer reported research which showed that in many vertebrate species, including the primates, the tremors and convulsions of the HPNS are dependent on compression rate. The HPNS seizure patterns are of such a nature that they indicate that their origin is not in the higher (i.e. cortical) levels of the brain but rather in the somewhat lower (i.e. subcortical) regions. In fact, some of the results on thermal perception and regulation in mice indicate that the relatively primitive portion of the brain (i.e. hypothalamus) might also be involved in the HPNS response.

In order to test the efficacy of trimix for human diving, various mixtures of oxygen, helium and nitrogen were tried at various pressures by Dr. Peter Bennett. Control helium-oxygen dives to 720 and 1000 feet with compression rates of 15 and 33 minutes respectively generated

marked HPNS. In comparison, including 10% nitrogen in the mixture at 1000 feet resulted in the subjects appearing, behaving and performing in an apparently normal manner. There was no euphoria and a minimal HPNS involvement. When diving to 1320 feet on a 6% nitrogen trimix, there was some mild tremor coupled with dizziness, nausea and persistent fatigue. Slowing the compression rate on a subsequent dive to a planned depth of 1600 feet, showed improved reactions as far down as 1300 feet but fatigue was so great at 1520 feet that the dive had to be aborted. Tremor as well as theta activity in the EEG were also increased while recovery of some of the decrements following the dive was quite prolonged. In view of these findings, a note of caution was sounded because of the inaccessibility of the divers in case treatment was required.

To help clarify the effects of helium compression on men a composite study by Dr. Christian Lambertsen was designed around rapid compression selected to induce effects, rather than to avoid them. Dive profiles involved a 50 minute compression to 800 feet followed by a two hour hold at that depth. Subjects were then compressed to 1200 feet. HPNS symptoms did occur but disappeared within one hour. The next day they were compressed from 1200 feet to 1600 feet within 20 minutes and were completely functional when reaching the bottom where they performed complex, underwater tasks with ease.

Synopsis of Discussion

By means of a short movie, Dr. Keith Miller made the point that animals at high pressure (approximately 150 ATA) could be stimulated into convulsing while anesthetized. From this he concluded that anesthesia and pressure act at two different sites in the body.

A question was raised as to whether there was any evidence of adaptation to HPNS. According to Dr. Ralph Brauer tremors do tend to subside during the exposure but there is no evidence of adaptation to HPNS even in those invertebrates who are deep dwelling marine organisms.

It was mentioned that during submarine escape experiments compression rates of 2500 feet/minute did not disrupt function and the query was made as to whether there was any comparable experience in deep diving. In answer to this, Dr. Bennett pointed out that the maximum submarine escape depth tested in these experiments was only 600 feet which was much shallower than the depth at which HPNS normally appeared. In addition the bottom time at the 600 feet was very brief to avoid inert gas uptake and nitrogen narcosis problems arising from

the use of compressed air. In the light of the very deep diving experiments carried out in other laboratories, Dr. Bennett questioned the minimal, transitory nature of HPNS symptoms in the divers reported by Dr. Lambertsen. The latter attributed his relative success to the experimental design of the diving studies.

A question was raised concerning the relationship between HPNS and oxygen convulsions. Both Dr. Brauer and Dr. E. Brian Smith felt that higher oxygen pressure lowered the HPNS threshold significantly but this occurred only, according to Dr. Brauer, when the partial pressure of oxygen exceeded 1.5 ATA.

FUTURE TRENDS

Chairman:	CAPT R. Bornmann, MC, USN
Rapporteur:	CDR C. Harvey, MC, USN
Members:	LCDR T. Berghage, MSC, USN Mr. W. Bergman CAPT G. Bond, MC, USN (Ret.) CDR M. Bradley, MC, USN Dr. J. Clark Dr. C. J. Lambertsen Dr. E. B. Smith CAPT J. Vorosmarti, MC, USN Dr. P. Webb

FUTURE TRENDS

Captain Robert Bornmann introduced the session by emphasizing that, as we press on to 1500 and 2000 feet diving capability, we should not overlook the need for extending working times and diving techniques within the 0 to 200 foot level, including the extension of minimal- and no-decompression limits at these depths. What is desired is not the minor improvements which can possibly be attained by re-phrasing the present Navy Air Tables, but an investigation of and application of new concepts. The application must also be compatible with Navy diving and must not be impracticably expensive.

Several participants (including Dr. Christian Lambertsen, CDR Albert Smith, Captain George Bond, Dr. Paul Webb and Dr. E. Brian Smith) then offered comments on diving conducted within the 0 to 200 foot range. Standard scuba gear will likely be continued in wide use in the Navy for sometime. The acquisition of closed circuit mixed gas scuba equipment will require some alteration of procedures developed for the Navy's pure oxygen closed circuit and mixed gas semi-closed circuit diving rigs. The need to expand the working capability of the diver for up to six hours at depths of up to 200 feet was identified. LCDR Thomas Berghage stated that optimization of breathing gas choices would significantly improve our operational capability within this area. Captain Bond described exploratory work in which four inert gases mixed with oxygen had significantly reduced decompression obligations and stated that a program was being developed at the University of Hawaii, the Naval Medical Research Institute and the Naval Submarine Medical Research Laboratory to continue these investigations. The sequential nature of problems arising during a dive, such as dry chamber compression, chilling on water entry and the diuresis which occurs upon entering the water were noted, and the need to consider such chains of events prior to the development of equipment was emphasized.

Dr. Bornmann mentioned the concern of the Secretary of the Navy for the protection of human subjects in Navy research and development, and noted that the potential benefit of any such undertaking must justify the risk or even discomfort to the subjects.

The Chairman then led the group into a discussion of the need for systematization of new diving technology within the Navy. A period of 10-15 years inevitably is required between the identification of a new operational concept and the completion of a development

program through fleet introduction. The Navy organization is set up to maintain the smooth progress of development toward established requirements and objectives despite program personnel changes. Success of any system is dependent upon the character of key personnel, and the recent important contributions of outstanding officers in the diving organization were applauded by the meeting participants.

Responding to a question regarding the lack of diving medical officers to fill a number of operational billets, Captain Herbert Glick stated that he hoped to see an improvement soon in this situation which exists Navy-wide, as the result of new policies by the Surgeon General to deal with this problem. For example, it is possible that new medical officers will in the future go first to a fleet operational billet prior to entering a Navy post-graduate training program. Captain Glick also felt there was a need to review the requirements for diving medical officer assignment, and possibly for a revision of submarine and diving medical training programs.

Various speakers emphasized the role of individuals as forces in the coordination of engineering, operating, biomedical, and basic science areas. The need for a flow of fresh ideas, as well as techniques and research findings was emphasized so that information would continue to be available after discovery and utilized. The role of the Undersea Medical Society, their Workshops, and the information storage and retrieval systems conducted in cooperation with this group were discussed and emphasized. Added participation in these medical meetings by individuals dedicated to the operational end of diving was strongly recommended. A path for input of new ideas from the commercial diving community was also urged. Several participants reemphasized the need for communication from the scientific world in a form the operational divers could utilize. Research results published in scientific journals are not, in that form, particularly useful to equipment designers or operators. An interpretative and judgmental function must be added continuously as part of the liaison between the different communities interested in diving.

The need for maintaining good communication between operational, engineering and medical communities in diving was agreed to by all participants. Navy diving has grown enormously since 1960 when all phases were carried out by a small group of individuals in the Washington Navy Yard with a budget of $100 thousand a year. It was recommended that the Office of the Chief of Naval Operations consider convening a "discussion group" of key individuals within the Navy headquarters in Washington to facilitate liaison and coordination of responsibilities in diving.

Future Trends

CDR Calvin Miller identified several areas where he felt research was justified from the operational point of view, including air purity standards, improved decompression schedules, improved guidelines for performance under thermal stress, thermal protection equipment, guidelines for handling occupational risks such as dysbaric osteonecrosis, and tables for decompression following exposures to contaminated atmospheres in bottomed submarines.

Mr. Walter Bergman spoke of the complexities in running a well-integrated development program and emphasized careful planning of all phases. He stated that funding must be provided for introduction of new equipment into the fleet after successful development. Problems with decompression and diver heating should be solved before development of deep diving or submarine rescue techniques. He also asked for better treatment techniques and for better matrices for exposure versus performance decrement.

Captain Bond then pointed out other areas for research including the role of perfusion limited gas exchange in conventional diving and diffusion limited gas exchange in saturation diving. He suggested examining the characteristics of the human lung as a heat exchange organ and studying the exchange of gases within the human body by techniques such as mass spectrometer probes within blood vessels and tissues. He also noted that many of the "folklore" impressions of certain diving tables and their safety needed further investigation.

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